

## PATENT ABSTRACTS OF JAPAN

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(71)Applicant : TOYODA GOSEI CO LTD

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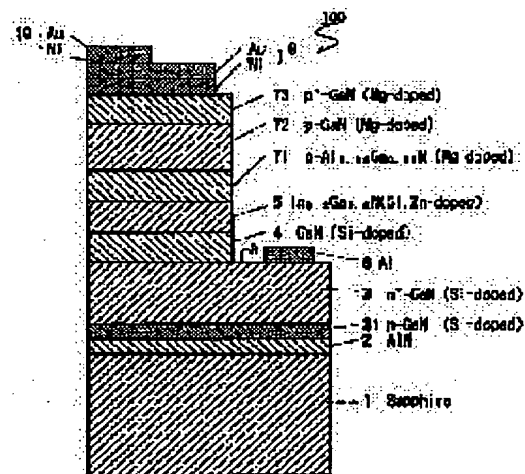
(72)Inventor : WATANABE HIROSHI  
ASAI MAKOTO  
SHIBATA NAOKI

## (54) III-GROUP NITROGEN COMPOUND SEMICONDUCTOR LIGHT EMITTING ELEMENT

## (57)Abstract:

**PROBLEM TO BE SOLVED:** To contemplate improvements in the increase of luminous intensity and luminous efficiency of a blue light emitting element.

**SOLUTION:** After a GaN n-layer having the film thickness of about  $0.6 \mu\text{m}$ , Si density of  $2 \times 10^{18}/\text{cm}^3$  and electron density of  $2 \times 10^{18}/\text{cm}^3$  has been formed on a buffer layer 2, a GaN high carrier density n+ layer (high impurity density layer) 3 having the film thickness of about  $4.0 \mu\text{m}$ , Si density of  $4 \times 10^{18}/\text{cm}^3$  and electron density of  $2 \times 10^{18}/\text{cm}^3$ , a GaN n-layer (second low impurity density layer) 4 having the film thickness of about  $0.5 \mu\text{m}$ , Si density of  $1 \times 10^{18}/\text{cm}^3$  and electron density of  $5 \times 10^{17}/\text{cm}^3$ , an  $\text{In}_{0.20}\text{Ga}_{0.80}\text{N}$  light emitting layer 5 having the film thickness of about 100nm, an  $\text{Al}_{0.08}\text{Ga}_{0.92}\text{N}$  P-conductive type clad layer 71, a GaN first contact layer 72, and a GaN p+ conductive type second contact layer 73 are successively formed on the n-layer 31. As a result, the crystallinity of the light emitting layer 5 can be improved by the n-layer (first low impurity density layer) 31, and as a contact electrode is formed on the n+ layer 3, resistance becomes small and the lowering of driving voltage and the improvement of light emitting efficiency can be accomplished.



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**CLAIMS**

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[Claim(s)]

[Claim 1] In the light emitting device which has n layers which consist of 3 group nitride semiconductor formed on the substrate, a luminous layer, and p layers The 1st low impurity concentration layer which added the impurity to the low concentration which contains impurity additive-free for the layer formed in the direction near the aforementioned substrate among the n aforementioned layers and the p aforementioned layers from the direction near the aforementioned substrate, The light emitting device which is formed on the 1st low impurity concentration layer, considers as the configuration which has the high impurity concentration layer which added the impurity to high concentration, and is characterized by forming a contact electrode to the aforementioned quantity impurity concentration layer.

[Claim 2] The light emitting device according to claim 1 characterized by forming the 2nd low impurity concentration layer which added the impurity to low concentration between the aforementioned quantity impurity concentration layer and the aforementioned luminous layer.

[Claim 3] The carrier concentration of the aforementioned 1st low impurity concentration layer is a light emitting device according to claim 1 or 2 characterized by being three or less  $2 \times 10^{18}/\text{cm}^3$ .

[Claim 4] the aforementioned 1st low impurity concentration layer thickness — 100 nm — it is — light emitting device according to claim 1 or 2 characterized by things

[Claim 5] The carrier concentration of the aforementioned quantity impurity concentration layer is a light emitting device according to claim 1 or 2 characterized by being  $1 \times 10^{16}$  to  $1 \times 10^{19}/\text{cm}^3$ .

[Claim 6] the aforementioned quantity impurity concentration layer thickness — 0.5–10 micrometers it is — light emitting device according to claim 1 or 2 characterized by things

[Claim 7] The impurity concentration of the aforementioned 1st low impurity concentration layer is a light emitting device according to claim 1 or 2 characterized by being three or less  $4 \times 10^{18}/\text{cm}^3$ .

[Claim 8] The layer formed in the direction near the aforementioned substrate is a light emitting device according to claim 1 to 7 characterized by being n layers which show n conduction type.

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**DETAILED DESCRIPTION**

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[Detailed Description of the Invention]

[0001]

[The technical field to which invention belongs] this invention relates to the semiconductor device which used 3 group nitride semiconductor. It is related with the light emitting device which raised photogenesis brightness especially.

[0002]

[Description of the Prior Art] It is AlGaInN as a material of the light emitting device of the former, blue, or a short wavelength field. The thing using the compound semiconductor of a system is known. Since the compound semiconductor is a transited [ directly ] type, it attracts attention from luminous efficiency making the luminescent color the blue and green which are one in three primary colors of a high thing and the light etc.

[0003] AlGaInN Also in a system semiconductor, Mg is doped, an electron ray is irradiated or-izing can be carried out [ p mold ] with heat treatment. Consequently, AlGaIn InGaIn of the clad layer of p conduction type, Zn, and Si dope A luminous layer and GaN The light emitting diode (Light Emitting Diode) which has the double hetero structure using n layers is known. n+ to which this light emitting diode added a buffer layer and silicon on silicon on sapphire at high concentration Type GaN n form GaN which added a layer and silicon The clad layer which consists of a layer, and InGaIn \*\*\*\* -- luminous layer and p type AlGaIn which changes Clad layer and p type GaN The 1st contact layer and p+ Type GaN The 2nd contact layer is formed.

[0004]

[Problem(s) to be Solved by the Invention] However, such light emitting diode of structure still had a problem of the parvus in a photogenesis intensity. Then, this invention persons found the following thing newly, as a result of repeating a research about the crystallinity of this light emitting device. n+ which added silicon on the buffer layer at high concentration Type GaN A layer is formed and the upper layer is formed one by one on it. Consequently, n+ Type GaN As a result of the layer's containing the impurity so much, it became clear that the crystallinity of each class by which crystallinity is not good, therefore is formed on it is not good, either. Then, except for the buffer layer, the crystallinity of each class formed on it became good, and that photogenesis brightness and luminous efficiency improve made clear the layer first formed on a substrate henceforth [ the layer then henceforth ] when the becoming \*\*\*\* impurity concentration is low.

[0005] Therefore, this invention is accomplished based on the above-mentioned knowledge, it is improving the crystallinity of each class of a light emitting device, and the purpose of this invention is raising photogenesis brightness and luminous efficiency.

[0006]

[Means for Solving the Problem] In the light emitting device which has n layers which consist of 3 group nitride semiconductor with which this invention was formed on the substrate, a luminous layer, and p layers The 1st low impurity concentration layer which added the impurity to the low concentration which contains impurity additive-free for the layer formed in the direction near a substrate among n layers and p layers from the direction near a substrate, It is formed on the 1st low impurity concentration layer, considers as the configuration which has the high impurity concentration layer which added the impurity to high concentration, and is characterized by forming a contact electrode to a high impurity concentration layer.

[0007] In the above-mentioned configuration, the 2nd low impurity concentration layer which added the impurity to low concentration may be formed between the high impurity concentration layer and the luminous layer. Since impurity concentration of the layer used as the footing into which a luminous layer is grown up was made low, the crystallinity of the layer is good, therefore the crystallinity of the luminous layer which grows on it also becomes good.

[0008] In the above-mentioned configuration, the carrier concentration of the 1st low impurity concentration layer has three or less desirable  $2 \times 10^{18}/\text{cm}^3$ . At this time, the crystallinity of each class formed on it is improved. Moreover, a low impurity concentration layer thickness is  $100 \sim 2 \mu\text{m}$ . It is desirable: 100 The effect of an improvement of crystallinity of each class formed on it if thinner than  $100 \mu\text{m}$  is low, and it is  $2 \mu\text{m}$ . If it becomes the above, since the thickness of each class which can grow on it, without generating a crack will be restricted, it is not desirable.

[0009] As for the carrier concentration of a high impurity concentration layer, in the above-mentioned configuration, it is desirable that it is  $1 \times 10^{16}$  to  $1 \times 10^{19}/\text{cm}^3$ . A contact electrode is formed in this layer. Therefore, since the crystallinity of the layer formed on it by crystallinity becoming bad will fall if carrier concentration is set to three or more  $1 \times 10^{19}/\text{cm}^3$  although this layer has resistivity as desirable as the parvus, it is not desirable. If carrier concentration is set to three or less  $1 \times 10^{16}/\text{cm}^3$ , since resistance cannot be reduced by the proper layer thickness, it is not desirable. moreover, the high impurity concentration layer thickness  $\sim 0.5 \sim 10$  micrometers it is  $\sim$  things are desirable  $0.5 \mu\text{m}$ . It becomes difficult and is not desirable to expose the layer by etching, if thin, and to form a contact electrode in the layer. Moreover, 10 micrometers Since it will become difficult to grow up each class formed on it, without generating a crack if thick, it is not desirable.

[0010] Furthermore, as for the impurity concentration of the 1st low impurity concentration layer, in the above-mentioned configuration, it is desirable that it is three or less  $4 \times 10^{18}/\text{cm}^3$ . If  $4 \times 10^{18}/\text{cm}^3$  is exceeded, since the crystallinity of each class formed on it will fall, impurity concentration is not desirable. Moreover, it is [ the manufacture ] easier to make the direction near a substrate into n layers, if it says from the point of p form activation, although n layers of n conduction type or p layers of p conduction type are sufficient as the layer formed in the direction near a substrate. When the layer of the direction near a substrate is made into n layers, the above-mentioned carrier concentration means concentration of electrons, and the above-mentioned impurity means a donor impurity. Moreover, when the layer of the direction near a substrate is made into p layers, the above-mentioned carrier concentration means hole concentration, and the above-mentioned impurity means acceptor impurity. n layers or at least p layers of the above-mentioned carrier concentration, impurity concentration, and the numerical domain of a layer thickness are desirable domains both, respectively.

[0011]

[Function and Effect of the Invention] Since the impurity concentration containing impurity additive-free used the layer used as the footing of growth of a luminous layer as the low layer as mentioned above, the crystallinity of the layer improves. Therefore, as a result of the crystallinity of each class formed on the 1st low impurity concentration layer improving and the crystallinity of a luminous layer becoming good especially, photogenesis brightness and luminous efficiency improved. Moreover, since impurity concentration formed the high layer on the 1st low impurity concentration layer and the contact electrode was prepared in the layer, in order not to pass the 1st impurity concentration layer, the sag by resistance and resistance loss are suppressed and luminous efficiency of a carrier improved.

[0012]

[Embodiments of the Invention] Hereafter, this invention is explained based on a concrete example. In addition, this invention is not limited to the following example. drawing 1 -- light emitting device 100 of this application example General drawing is shown. Light emitting device 100 It has silicon on sapphire 1 and is  $0.05 \sim$ micrometer AlN on the silicon on sapphire 1. The buffer layer 2 is formed.

[0013] the buffer layer 2 top -- order -- thickness  $0.6 \sim$  [ about ]  $\mu\text{m}$  Silicon (Si) dope GaN of  $2 \times 10^{18}/\text{cm}^3$  of silicon concentration, and  $1 \times 10^{18}/\text{cm}^3$  of concentration of electrons \*\*\*\* -- n layer (1st low impurity concentration layer) 31 and the thickness  $4.0 \sim$  [ about ]  $\mu\text{m}$  which change  $\mu\text{m}$  --  $4 \times 10^{18}/\text{cm}^3$  of silicon concentration, and the concentration of electrons 2 The silicon (Si) dope GaN of  $1 \times 10^{18}/\text{cm}^3$  high carrier concentration  $n^+$  since -- it changes -- A layer (Quantity impurity concentration layer) 3 and thickness  $0.5 \sim$  [ about ]  $\mu\text{m}$  The silicon concentration 1 of  $\mu\text{m}$  GaN of the silicon (Si) dope of  $1 \times 10^{18}/\text{cm}^3$  and  $5 \times 10^{17}/\text{cm}^3$  of concentration of electrons \*\*\*\* -- about  $100\text{nm}$  of n layer

(2nd low impurity concentration layer) 4 and thickness and zinc (Zn) which change, and a silicon (Si) dope, respectively. In  $0.20\text{Ga}0.80\text{N}$  doped by  $5 \times 10^{18}/\text{cm}^3$  \*\*\*\* -- the luminous layer 5 which changes, about 10nm of thickness, and hole concentration  $2 \times 10^{17}/\text{cm}^3$ , Magnesium (Mg) Concentration  $5 \times 10^{19}/\text{cm}^3$  dope aluminum  $0.08\text{Ga}0.92\text{N}$  since -- the clad layer 71 of p conduction type which changes, about 35nm of thickness, and hole concentration Magnesium (Mg) concentration of  $3 \times 10^{17}/\text{cm}^3$  GaN of  $5 \times 10^{19}/\text{cm}^3$  dope \*\*\*\* -- the 1st contact layer 72 which changes, thickness about 5 nm, and hole concentration magnesium (Mg) of  $6 \times 10^{17}/\text{cm}^3$  Concentration GaN of  $1 \times 10^{20}/\text{cm}^3$  dope \*\*\*\* -- p+ which changes The 2nd contact layer 73 of conduction type is formed. the [ and ] -- the top whole of 2 contact layer 73 -- nickel/Au the transparent electrode 9 which consists of a double layer forms -- having -- the fraction of the corner of the transparent electrode 9 -- nickel/Au The pad 10 for the bonding which consists of a double layer is formed. Moreover, n+ The electrode 8 which consists of aluminum is formed on the layer 3.

[0014] Next, the manufacture technique of the semiconductor device of this structure is explained. The above-mentioned light emitting device 100 It was manufactured by the vapor growth by the organic-metal vapor growth (following MOVPE). The used gas Ammonia ( $\text{NH}_3$ ) and carrier gas ( $\text{H}_2$ ), trimethylgallium ( $\text{Ga}(\text{CH}_3)_3$ ) (it is described as "TMG" below) trimethylaluminum (aluminum  $3(\text{CH}_3)$ ) (it is described as "TMA" below) trimethylindium ( $\text{In}(\text{CH}_3)_3$ ) (it is described as "TMI" below) A silane ( $\text{SiH}_4$ ) and diethylzinc ( $\text{Zn}(\text{C}_2\text{H}_5)_2$ ) (it is described as "DEZ" below) It is magnesium cyclopentadienyl ( $\text{Mg}(\text{C}_5\text{H}_5)_2$ ) (it is described as "CP2Mg" below).

[0015] First, the a-th page washed with organic washing and heat treatment is made into a principal plane, and it is MOVPE about the silicon on sapphire 1 of a single crystal. The susceptor laid in the reaction chamber of equipment is equipped. Next, silicon on sapphire 1 was baked at the temperature of 1100 degrees C, passing  $\text{H}_2$  to a reaction chamber for about 30 minutes by part for rate-of-flow 2 liter/by the ordinary pressure.

[0016] Next, temperature It is made to fall to 400 degrees C, and they are a part for 20 liter/, and  $\text{NH}_3$  about  $\text{H}_2$ . A part for 10 liter/, and TMA It supplies for about 90 seconds by part for  $1.8 \times 10^{-5}$  mols/, and is AlN. The buffer layer 2 was formed in thickness of about 0.05 micrometers. Next, it is 1100 degreeC about the temperature of silicon on sapphire 1. It holds.  $\text{H}_2$  A part for 20 liter/,  $\text{NH}_3$  A part for 10 liter/, and TMG A part for  $1.12 \times 10^{-4}$  mols/,  $\text{H}_2$  gas -- 0.86 ppm the diluted silane -- a part for  $20 \times 10^{-9}$  mols/-- 36 minutes -- introducing -- thickness 0.6 [ about ] mum and concentration of electrons  $1 \times 10^{18}/\text{cm}^3$  and silicon concentration Silicon (Si) dope GaN of  $2 \times 10^{18}/\text{cm}^3$  \*\*\*\* -- n layer 31 which changes was formed

[0017] The temperature of silicon on sapphire 1 is held at 1150 degrees C.  $\text{H}_2$  A part for next, 20 liter/,  $\text{NH}_3$  A part for 10 liter/, and TMG A part for  $1.7 \times 10^{-4}$  mols/, It is 0.86 ppm by  $\text{H}_2$  gas. The diluted silane is introduced by part for  $20 \times 10^{-8}$  mols/for 40 minutes. thickness 4.0 [ about ] mum and concentration of electrons  $1 \times 10^{18}/\text{cm}^3$  and silicon concentration Silicon (Si) dope GaN of  $4 \times 10^{18}/\text{cm}^3$  \*\*\*\* -- high carrier concentration n+ which changes The layer 3 was formed.

[0018] Above-mentioned high carrier concentration n+ After forming a layer 3, it is 1100 degreeC about temperature continuously. It holds. They are a part for 20 liter/, and  $\text{NH}_3$  about  $\text{H}_2$ . A part for 10 liter/, and TMG A part for  $1.12 \times 10^{-4}$  mols/,  $\text{H}_2$  gas -- 0.86 ppm the diluted silane -- a part for  $10 \times 10^{-9}$  mols/-- 30 minutes -- introducing -- thickness 0.5 [ about ] mum and concentration of electrons  $5 \times 10^{17}/\text{cm}^3$  and silicon concentration Silicon (Si) dope GaN of  $1 \times 10^{18}/\text{cm}^3$  \*\*\*\* -- n layer 4 which changes was formed

[0019] Temperature is held to 800 \*\*.  $\text{N}_2$  or  $\text{H}_2$  A part for then, 20 liter/,  $\text{NH}_3$  A part for 10 liter/, and TMG  $0.2 \times 10^{-4}$  mol a part for /and TMI It is 0.86 ppm by  $1.6 \times 10^{-4}$  mol a part for /and  $\text{H}_2$  gas. The diluted silane by part for  $10 \times 10^{-8}$  mol/ DEZ  $2 \times 10^{-4}$  mols/a part -- for 30 minutes -- supplying -- 100nm in thickness silicon and zinc -- respectively --  $5 \times 10^{18}/\text{cm}^3$  -- dope \*\*\*\* In  $0.20\text{Ga}0.80\text{N}$  \*\*\*\* -- the luminous layer 5 which changes was formed

[0020] Temperature is held at 1100 degrees C.  $\text{N}_2$  or  $\text{H}_2$  A part for then, 20 liter/,  $\text{NH}_3$  A part for 10 liter/, and TMG A part for  $1.12 \times 10^{-4}$  mols/, TMA  $0.47 \times 10^{-4}$  mol a part for /and CP2Mg a part for  $2 \times 10^{-5}$  mols/-- 0.6 a part -- between -- introducing -- aluminum  $0.08\text{Ga}0.92\text{N}$  of the magnesium (Mg) dope of about 10nm of thickness \*\*\*\* -- the clad layer 71 which changes was formed Magnesium concentration of the clad layer 71 It is  $5 \times 10^{19}/\text{cm}^3$ . In this status, the clad layer 71 is still resistivity 108. It is an insulator more than  $\Omega\text{cm}$ .

[0021] next, temperature -- 1100 degrees C -- holding -- N<sub>2</sub> or H<sub>2</sub> -- a part for 20 liter/, and NH<sub>3</sub> A part for 10 liter/, and TMG 1.12x10<sup>-4</sup> mol a part for /and CP2Mg a part for 2x10<sup>-5</sup> mols/-- for 40 seconds -- introducing -- GaN of the magnesium (Mg) dope of about 35nm of thickness \*\*\*\* -- the 1st contact layer 72 which changes was formed Magnesium concentration of the 1st contact layer 72 It is 5x10<sup>19</sup>/cm<sup>3</sup>. In this status, the 1st contact layer 72 is still resistivity 108. It is an insulator more than omegacm.

[0022] next, temperature -- 1100 degrees C -- holding -- N<sub>2</sub> or H<sub>2</sub> -- a part for 20 liter/, and NH<sub>3</sub> A part for 10 liter/, and TMG 1.12x10<sup>-4</sup> mol a part for /and CP2Mg a part for 4x10<sup>-5</sup> mols/-- for 18 seconds -- introducing -- GaN of the magnesium (Mg) dope of thickness about 5 nm \*\*\*\* -- p+ which changes The 2nd contact layer 73 was formed. Magnesium concentration of the 2nd contact layer 73 It is 1x10<sup>20</sup>/cm<sup>3</sup>. In this status, the 2nd contact layer 73 is still resistivity 108. It is an insulator more than omegacm.

[0023] Next, the electron ray was uniformly irradiated at the 2nd contact layer 73, the 1st contact layer 72, and the clad layer 71 using electron-beam-irradiation equipment. The irradiation conditions of an electron ray are 0.2mm of the traveling speeds of about 10kV of acceleration voltage, 1micro A of data currents, and a beam, sec, beam-diameter 60micrometerphi, and degree of vacuum 5.0 x10<sup>-5</sup>Torr. By irradiation of this electron ray, the 2nd contact layer 73, the 1st contact layer 72, and the clad layer 71 are hole concentration, respectively. 6x10<sup>17</sup>/cm<sup>3</sup>, 3x10<sup>17</sup>/cm<sup>3</sup>, 2x10<sup>17</sup>/cm<sup>3</sup>, resistivity 2ohmcm and 1 It became p conduction-type semiconductor of omegacm and 0.7ohmcm. Thus, the wafer of multilayer structure was obtained.

[0024] Next, as shown in drawing 2 , the Ti (titanium) layer 111 is formed with vacuum deposition on the 2nd contact layer 73 at thickness 1000\*\*, and it is 1 micrometer in thickness about the nickel (nickel) layer 112 on it. It forms. And a photoresist 12 is applied on the nickel layer 112, with a \*\*\*\*\* graph, as shown in drawing 2 , it sets on the 2nd contact layer 73, and it is high carrier concentration n+. Electrode formation site A' to a layer 3 The photoresist 12 was removed. Next, as shown in drawing 3 , wet etching of the Ti layer 111 and the nickel layer 112 which are not covered by the photoresist 12 was carried out, and the acid removed them.

[0025] Next, the 2nd contact layer 73 of the site which is not covered by the Ti layer 111 and the nickel layer 112, the 1st contact layer 72, the clad layer 71, and 5 or n layers of luminous layers, after carrying out dry etching of 4 by BCl<sub>3</sub> gas, dry etching of it was carried out by Ar. this process shows to drawing 4 -- as -- high carrier concentration n+ the hole for electrode extraction to a layer 3 -- A was formed Then, the photoresist 12, the Ti layer 111, and the nickel layer 112 as a mask were removed.

[0026] Next, after applying a photoresist uniformly, the aperture was opened in the fraction which forms a transparent electrode 9 according to the photo-lithography process. Then, it is nickel/Au uniformly. The vacuum evaporatio of two-layer was carried out, and the photoresist was removed, namely, the transparent electrode 9 was formed on the 2nd contact layer 73 by the lift-off method. And it is nickel/Au in a part of the transparent electrode 9. The vacuum evaporatio of two-layer was carried out, and the pad 10 was formed. On the other hand, it is n+. To the layer 3, according to the same process, the vacuum evaporatio of the aluminum was carried out and the electrode 8 was formed. Then, like the above, the processed wafer is cut for every element and obtained the light emitting diode of the structure shown in drawing 1 . this light emitting device -- 20mA of drive currents -- emission-peak-wavelength 430 nm and photogenesis on-the-strength 1500mCd it was . Compared with Light Emitting Diode of structure, the photogenesis intensity increased 3 times conventionally.

[0027] In addition, GaN The surface morphology of the 2nd contact layer 73 of the best layer at the time of preparing 31 [ n-layer ] and forming the light emitting device of the above-mentioned configuration was observed under the microscope. The surface microphotography is shown in drawing 5 . Moreover, they are direct and n+ on the buffer layer 2, without preparing 31 [ n-layer ] like the conventional light emitting device. The surface morphology of the 2nd contact layer 73 of the best layer at the time of forming a layer 3 and forming a light emitting device was observed under the microscope. The surface microphotography is shown in drawing 6 . All are 200 times as many microphotographies as this.

[0028] It is understood that crystallinity is [ the direction which 31 / n-layer / was prepared / direction / and carried out the laminating of each class on it ] good so that this photograph may show.

[0029] It sets in the above-mentioned example and is 4 n layers High carrier concentration n+ Although

formed between a layer 3 and the luminous layer 5, it is high carrier concentration  $n^+$ . When the impurity carrier concentration of a layer 3 is comparatively low, it is high carrier concentration  $n^+$ . You may grow up a luminous layer 5 directly on a layer 3. In the above-mentioned example, although silicon is added in  $2 \times 10^{18}/\text{cm}^3$  and  $n$  layers of concentration of electrons are set to  $1 \times 10^{18}/\text{cm}^3$  31, you may be additive-free. It is checked that the crystallinity of each class on which silicon concentration grows to be  $2 \times 10^{18}/\text{cm}^3$ , and concentration of electrons grows on it rather than  $1 \times 10^{18}/\text{cm}^3$  at the time of the parvus becomes good.

[0030] Furthermore, the thickness of 31 is 0.6  $n$  layers.  $\mu\text{m}$  Since  $n$  layers exist in order that 31 may improve the crystallinity of each class which grows one by one on it although carried out, it is  $100 \times 2$ .  $\mu\text{m}$  It is checked that there is an effect of an improvement of crystallinity in the domain. It sets in the above-mentioned example and is high carrier concentration  $n^+$ . Although the carrier concentration of a layer 3 set  $2 \times 10^{18}/\text{cm}^3$  and silicon concentration to  $4 \times 10^{18}/\text{cm}^3$ , carrier concentration is  $1 \times 10^{16}$  to  $1 \times 10^{19}/\text{cm}^3$ , silicon concentration is the domain of  $1 \times 10^{17}$  to  $1 \times 10^{20}/\text{cm}^3$ , the crystallinity of the layer which grows on it can be improved, and resistance can be made small. Moreover, high carrier concentration  $n^+$  It is the thickness of a layer 3 4.0  $\mu\text{m}$  Although carried out, it is the high carrier concentration  $n^+$  from the same viewpoint as carrier concentration. The thickness of a layer 3 is 0.5–10 micrometers. The domain is the optimum.

[0031] Although 4 set  $n$  layers to  $1 \times 10^{18}/\text{cm}^3$  of silicon concentration, and  $5 \times 10^{17}/\text{cm}^3$  of concentration of electrons, it is  $2 \times 10^{16}$  to  $2 \times 10^{19}/\text{cm}^3$  of silicon concentration. Concentration of electrons  $1 \times 10^{16}$  –  $1 \times 10^{19}/\text{cm}^3$  It is a suitable domain. Moreover, thickness is 0.5. Although referred to as  $\mu\text{m}$ , 0.5 to 2 micrometer is desirable. if a thickness is set to 0.5 micrometers or less, a photogenesis intensity will fall — since it will generate heat if series resistance will become high too much if set to 2 or more micrometers, and a current is passed, it is not desirable.

[0032] In the above-mentioned example, although the contact layer was made into two-layer structure, one layer structure is sufficient as it. In a luminous layer 5, it is  $\text{In}_{0.20}\text{Ga}_{0.80}\text{N}$ .  $\text{InGaAlN}$  which are 2 yuan, 3 yuan, and 4 yuan although used If it is 3 group nitride semiconductor, the composition ratio of a configuration element can use arbitrary things. Moreover, about the clad layer 71, the 1st contact layer 72, and the 2nd contact layer 73, the semiconductor with a band gap larger than a luminous layer 5 is demanded. The layer of \*\*\*\*\* can also use 3 group nitride semiconductor of 2 yuan, 3 yuan, and 4 yuan. Moreover,  $n$  layer 31 and  $n^+$  4 is general formula  $\text{InGaAlN}$  similarly 3 or  $n$  layers of layers. 3 group nitride semiconductor of 2 yuan of an arbitrary composition ratio, 3 yuan, and 4 yuan can be used.

[0033] Moreover, the silicon concentration and zinc concentration of a luminous layer 5 have desirable  $1 \times 10^{17}$  to  $1 \times 10^{20}/\text{cm}^3$  respectively.  $1 \times 10^{17}/\text{cm}^3$  When it is the following, luminous efficiency falls with the shortage of an emission center, and it is  $1 \times 10^{20}/\text{cm}^3$ . If it becomes the above, since crystallinity will become bad and the Auger effect will occur, it is not desirable. It is  $1 \times 10^{18}$  to  $1 \times 10^{19}/\text{cm}^3$  still preferably. A domain is good. moreover, the concentration of silicon (Si) — zinc (Zn) — comparing — 10 time  $-1/10$  — desirable — further — desirable — A between  $[1 - 1/10]$  grade and the fewer one is more desirable.

[0034] Although the monolayer constituted the luminous layer 5 from the above-mentioned example General formula  $\text{Al}_{x1}\text{Ga}_{y1}\text{In}_{1-x1-y1}$  The well layer of N ( $0 \leq x1 \leq 1, 0 \leq y1 \leq 1, 0 \leq x1+y1 < 1$ ), and general formula  $\text{Al}_{x2}\text{Ga}_{y2}\text{In}_{1-x2-y2}\text{N}$  ( $0 \leq x2 \leq 1, 0 \leq y2 \leq 1, 0 \leq x2+y2 < 1$ ) it consists of the barrier layer of  $\leq 1$  — you may constitute in single or multiplex quantum well structure In this case, a donor impurity and acceptor impurity may be simultaneously added in a well layer or a barrier layer, a donor impurity or acceptor impurity may be added in a well layer, and acceptor impurity or a donor impurity may be conversely added in a barrier layer. Moreover, this invention can be used also for a laser diode besides light emitting diode.

[0035] The beryllium (Be) of 2 group element, magnesium (Mg), zinc (Zn), cadmium (Cd), and mercury (Hg) may be used for acceptor impurity. Carbon which is 4 group element as a donor impurity when 2 group element is made into acceptor impurity (C) Silicon (Si) germanium \*\*\*\*\* (germanium), tin (Sn), and lead (Pb) can be used. Moreover, when 4 group element is made into acceptor impurity, it is the sulfur (S) of 6 group element as a donor impurity. A selenium (Se) and a tellurium (Te) can also be used. Heat treatment in a heat annealing besides an electron beam irradiation and  $\text{N}_2$  plasma gas and laser radiation can perform p mold-ization.

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**DESCRIPTION OF DRAWINGS**

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[Brief Description of the Drawings]

[Drawing 1] The block diagram having shown the configuration of the light emitting diode concerning the 1st concrete example of this invention.

[Drawing 2] The cross section having shown the manufacturing process of the light emitting diode of this example.

[Drawing 3] The cross section having shown the manufacturing process of the light emitting diode of this example.

[Drawing 4] The cross section having shown the manufacturing process of the light emitting diode of this example.

[Drawing 5] The microphotography which observed the surface state of the best layer at the time of forming the 1st low impurity concentration layer (n layers) in the above-mentioned light emitting diode.

[Drawing 6] The microphotography which observed the surface state of the best layer in the case of not forming the 1st low impurity concentration layer (n layers) in light emitting diode.

[Description of Notations]

100 — Semiconductor Device

1 — Silicon on sapphire

2 — Buffer layer

31 — n layers (the 1st low impurity layer)

3 — Quantity carrier concentration n<sup>+</sup> Layer (quantity impurity layer)

4 — n layers (the 2nd low impurity layer)

5 — Luminous layer

6 — Cap layer

71 — Clad layer

72 — The 1st contact layer

73 — The 2nd contact layer

8 — Electrode

9 — Transparent electrode

10 — Pad

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[Translation done.]



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**DETAILED DESCRIPTION**

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[Detailed Description of the Invention]

[0001]

[The technical field to which invention belongs] this invention relates to the light emitting device using 3 group nitride semiconductor which raised electrostatic pressure-proofing of the right orientation.

[0002]

[Description of the Prior Art] In  $\text{In}_1\text{-XGaXN}$  which added Zn and Si as a 3 group nitride semiconductor light emitting device conventionally \*\*\*\* — the luminous layer which changes — hole concentration  $\text{AlGaIn}$  of three or less  $1 \times 10^{18}/\text{cm}^3$  p conduction type \*\*\*\* — p becoming layers and concentration of electrons  $\text{GaIn}$  of  $2 \times 10^{18}/\text{cm}^3$  \*\*\*\* — the thing of the double hetero structure inserted by n layers which change is known This light emitting device is 420–520nm. Blue photogenesis is obtained.

[0003]

[Problem(s) to be Solved by the Invention] However, the light emitting device of the above-mentioned configuration has the hole concentration of p layers as small as three or less  $1 \times 10^{18}/\text{cm}^3$ , and since the carrier concentration of a barrier layer is comparatively as high as  $5 \times 10^{17}$  to  $2 \times 10^{18}/\text{cm}^3$ , the thickness of a depletion layer is very narrow [ a light emitting device ]. For this reason, this light emitting device has the problem that the about [ 100V ] right voltage of the right orientation destroys easily.

[0004] this invention is accomplished in order to solve the above-mentioned technical problem, and the purpose is raising the dielectric-breakdown-proof nature to the right voltage of the right orientation.

[0005]

[Means for Solving the Problem] this invention is high carrier concentration  $n^+$  of n conduction type. A layer, a luminous layer, and p layers of p conduction type set to the light emitting device formed with 3 group nitride semiconductor, and it is luminous layer and high carrier concentration  $n^+$ . Between layers, it is luminous layer and high carrier concentration  $n^+$ . It is characterized by preparing n layers which consist of 3 group nitride semiconductor of n conduction type with concentration of electrons lower than a layer.

[0006] Moreover, other characteristic features of invention are having constituted the n layers from a 3 group nitride semiconductor of n conduction type of  $5 \times 10^{16}$  to  $5 \times 10^{17}/\text{cm}^3$  of thickness 500 – 6000\*\* and carrier concentration. Furthermore, other characteristic features of invention are n layers and high carrier concentration  $n^+$ . It is GaN about a layer. It is having constituted.

[0007]

[Function and Effect of the Invention] As mentioned above, a luminous layer and  $n^+$  Between layers, it is luminous layer and high carrier concentration  $n^+$ . Since n layers which consist of 3 group nitride semiconductor of n conduction type with concentration of electrons lower than a layer were prepared, when the static voltage of the right orientation is impressed, the electric field between each class become small, and electrostatic pressure-proofing of the right orientation improves. Moreover, as for n layers, it is desirable to consider as 3 group nitride semiconductor of n conduction type of  $5 \times 10^{16}$  to  $5 \times 10^{17}/\text{cm}^3$  of thickness 500 – 6000\*\* and carrier concentration, and electrostatic pressure-proofing of the right orientation which is 500V was obtained. This value is the electrostatic pressure-proofing [ 5 times ] of the right orientation of the light emitting device of the conventional structure.

[0008]

[Example]

In 1st example view 1, light emitting diode 10 has silicon on sapphire 1, and it is AlN of 500 \*\* on the

silicon on sapphire 1. The buffer layer 2 is formed. the buffer layer 2 top — order — thickness 2.0 [ about ] Silicon dope GaN of mum and  $2 \times 10^{18}/\text{cm}^3$  of concentration of electrons \*\*\*\* — high carrier concentration  $n^+$  which changes a layer 3 and thickness 3000\*\* — concentration of electrons GaN of the silicon dope of  $1 \times 10^{17}/\text{cm}^3$  \*\*\*\* — In<sub>0.08</sub>Ga<sub>0.92</sub>N of about 0.05 micrometers of n layer 4 and thicknesss which change \*\*\*\* — the luminous layer 5 and the thickness 1.0 [ about ] which change mum — aluminum<sub>0.08</sub>Ga<sub>0.92</sub>N by which magnesium was doped by  $5 \times 10^{17}/\text{cm}^3$  of hole concentration, and  $1 \times 10^{20}/\text{cm}^3$  of concentration \*\*\*\* — p layer 61 and the thickness 0.2 [ about ] which change mum — hole concentration  $7 \times 10^{17}/\text{cm}^3$  and magnesium concentration GaN of the magnesium dope of  $2 \times 10^{20}/\text{cm}^3$  \*\*\*\* — the contact layer 62 which changes is formed And on the contact layer 62, the electrode 7 which consists of nickel joined to the layer 62 is formed. Furthermore, high carrier concentration  $n^+$  A part of front face of a layer 3 is exposed, and the electrode 8 which consists of nickel joined to the layer 3 is formed on the outcrop.

[0009] Next, the manufacture technique of the light emitting diode 10 of this structure is explained. The above-mentioned light emitting diode 10 is an organometallic compound vapor growth (it is described as "MOVPE" below). It was manufactured by the vapor growth to depend. The used gas NH<sub>3</sub> and trimethylindium (below) Carrier gas H<sub>2</sub> or N<sub>2</sub> (In<sub>3</sub> (CH<sub>3</sub>)) Trimethylgallium (Ga<sub>3</sub> (CH<sub>3</sub>)) (it is described as "TMG" below) Trimethylaluminum (aluminum<sub>3</sub> (CH<sub>3</sub>)) (it is described as "TMA" below) [ "TMI" ] It is described as ". They are a silane (SiH<sub>4</sub>) and magnesium cyclopentadienyl (Mg<sub>2</sub> (C<sub>5</sub>H<sub>5</sub>)) (it is described as "CP2Mg" below).

[0010] First, thickness 100–400 which makes a principal plane the a-th page washed with organic washing and heat treatment It is MOVPE about the silicon on sapphire 1 of the single crystal of mum. The susceptor laid in the reaction chamber of equipment is equipped. Next, gas phase etching of the silicon on sapphire 1 was carried out at the temperature of 1100 degrees C, passing H<sub>2</sub> to a reaction chamber by part for rate-of-flow 2 liter/by the ordinary pressure.

[0011] Next, temperature It is made to fall to 400 degrees C, and they are a part for 20 liter/, and NH<sub>3</sub> about H<sub>2</sub>. A part for 10 liter/, and TMA It supplies by part for  $1.8 \times 10^{-5}$  mols/, and is AlN. The buffer layer 2 is abbreviation. It was formed in the thickness of 500\*\*. The temperature of silicon on sapphire 1 is held at 1150 degrees C. H<sub>2</sub> A part for next, 20 liter/, NH<sub>3</sub> A part for 10 liter/, and TMG It is 0.86 ppm by part for  $1.7 \times 10^{-4}$  \*\*/, and H<sub>2</sub> gas. The diluted silane is supplied by part for  $20 \times 10^{-8}$  mol/for 30 minutes. thickness 2.2 [ about ] mum and concentration of electrons GaN of the silicon dope of  $2 \times 10^{18}/\text{cm}^3$  \*\*\*\* — high carrier concentration  $n^+$  which changes The layer 3 was formed.

[0012] The temperature of silicon on sapphire 1 is held at 1150 degrees C. N<sub>2</sub> or H<sub>2</sub> A part for next, 10 liter/, NH<sub>3</sub> A part for 10 liter/, and TMG Silane diluted by 0.86 ppm by  $1.12 \times 10^{-4}$  mol a part for /and H<sub>2</sub> gas By part for  $1 \times 10^{-8}$  mol/ 4 minutes — supplying — GaN of thickness about 3000\*\* and the silicon dope of  $1 \times 10^{17}/\text{cm}^3$  of concentration \*\*\*\* — n layer 4 which changes was formed

[0013] then, temperature — 850 \*\* — holding — N<sub>2</sub> or H<sub>2</sub> — a part for 20 liter/, and NH<sub>3</sub> A part for 10 liter/, and TMG  $1.53 \times 10^{-4}$  mol a part for /and TMI a part for  $0.02 \times 10^{-4}$  mols/— 6 a part — between — supplying — In<sub>0.08</sub>Ga<sub>0.92</sub>N [ 0.05-micrometer ] \*\*\*\* — the luminous layer 5 which changes was formed

[0014] Temperature is held at 1100 degrees C. N<sub>2</sub> or H<sub>2</sub> A part for then, 20 liter/, NH<sub>3</sub> A part for 10 liter/, and TMG A part for  $1.12 \times 10^{-4}$  mols/, TMA  $0.47 \times 10^{-4}$  mol a part for /and CP2Mg a part for  $2 \times 10^{-4}$  mols/— for 60 minutes — introducing — thickness 1.0 [ about ] aluminum<sub>0.08</sub>Ga<sub>0.92</sub>N of the magnesium (Mg) dope of mum \*\*\*\* — p layer 61 which changes was formed p layers of the concentration of the magnesium of 61 are  $1 \times 10^{20}/\text{cm}^3$ . In this status, 61 is still resistivity 108 p layers. It is an insulator more than omegacm.

[0015] then, temperature — 1100 degrees C — holding — N<sub>2</sub> or H<sub>2</sub> — a part for 20 liter/, and NH<sub>3</sub> A part for 10 liter/, and TMG  $1.12 \times 10^{-4}$  mol a part for /and CP2Mg a part for  $4 \times 10^{-4}$  mols/— comparatively — coming out — for 4 minutes — introducing — thickness 0.2 [ about ] GaN of the magnesium (Mg) dope of mum \*\*\*\* — the contact layer 62 which changes was formed Concentration of the magnesium of the contact layer 62 It is  $2 \times 10^{20}/\text{cm}^3$ . In this status, the contact layer 62 is still resistivity 108. It is an insulator more than omegacm.

[0016] Thus, the wafer of the cross-section structure shown in drawing 2 was obtained. Next, this wafer was heat-treated for 45 minutes at 450 degrees C. By this heat treatment, 61 is hole concentration 62 or p layers of contact layers, respectively.  $7 \times 10^{17}/\text{cm}^3$ ,  $5 \times 10^{17}/\text{cm}^3$ , resistivity 20hmcm and 0.8

omacm It bec p conduction-type semiconductor. Thus, the wafer of multilayer structure was obtained.

[0017] Next, it is shown in drawing 3 — as — the contact layer 62 top — sputtering — SiO two-layer — 9 was formed in the thickness of 2000\*\* and the photoresist 10 was applied on the SiO two-layer 9 And with a \*\*\*\*\* graph, as shown in drawing 3 , it sets on the contact layer 62, and it is high carrier concentration n+. Electrode formation site A' to a layer 3 The photoresist 10 was removed. next, the SiO two-layer which is not covered by the photoresist 10 as shown in drawing 4 — 9 was removed by the hydrofluoric-acid system etching reagent

[0018] Next, after 4 supplied and carried out dry etching of 2 and the BCl<sub>3</sub> gas at a rate for 10 ml/degree of vacuum 0.04Torr and 0.44W [ /cm ] RF power 5 or n layers of 62 or p layers 61 and the luminous layers of the contact layers of the site which is not covered by the photoresist 10 and SiO two-layer 9, dry etching was carried out by Ar. this process shows to drawing 5 — as — high carrier concentration n+ the hole for electrode extraction to a layer 3 — A was formed

[0019] Next, as the vacuum evaporations of the nickel is carried out uniformly, it passes through an application of a photoresist, a photolithography process, and an etching process all over the upper [ of a sample ] and it is shown in drawing 1 , it is high carrier concentration n+. The electrodes 8 and 7 to the layer 3 and the contact layer 62 were formed. Then, like the above, the processed wafer was cut for each chip and the light emitting diode chip was obtained.

[0020] Thus, photogenesis \*\*\*\*\* of the obtained light emitting device was measured. it is shown in drawing 6 — as — 20mA of drive currents — 450nm of emission peak wavelengths — photogenesis on-the-strength 1000mcd it was . Thus, the static voltage was impressed to the manufactured light emitting diode in the right orientation, and the electrostatic pressure-proofing was measured. Dielectric breakdown was not seen even if it impressed the static voltage of 500V. This is a luminous layer 5 and n+. Between layers 3, concentration of electrons is a luminous layer and n+. Since n layers lower than a layer 3 were prepared, it is considered because the electric field between each class by the right voltage of the right orientation become small.

[0021] The band gap of a luminous layer 5 is formed in a double heterojunction which exists in both sides and which becomes smaller than the band gap of 4 n layers with 61 p layers in the above-mentioned example. Moreover, the component ratio of 61 is [ a luminous layer 5 and ] GaN p layers. High carrier concentration n+ It is chosen so that it may be in agreement with the lattice constant of a layer. Moreover, although double heterojunction structure was used in the above-mentioned example, you may be single heterojunction structure. Furthermore, although the example of light emitting diode was shown, the above-mentioned example can be similarly constituted, even if it is a laser diode.

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**DESCRIPTION OF DRAWINGS**

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[Brief Description of the Drawings]

[Drawing 1] The block diagram having shown the configuration of the light emitting diode concerning the 1st concrete example of this invention.

[Drawing 2] The cross section having shown the manufacturing process of the light emitting diode of this example.

[Drawing 3] The cross section having shown the manufacturing process of the light emitting diode of this example.

[Drawing 4] The cross section having shown the manufacturing process of the light emitting diode of this example.

[Drawing 5] The cross section having shown the manufacturing process of the light emitting diode of this example.

[Description of Notations]

10 -- Light emitting diode

1 -- Silicon on sapphire

2 -- Buffer layer

3 -- Quantity carrier concentration n+ Layer

4 -- n layers

5 -- Luminous layer

61 -- p layers

62 -- contact layer

7, 8 -- Electrode

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[Translation done.]

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(71) 出願人

000241463

豊田合成株式会社

愛知県西春日井郡春日町大字落合字長畑 1  
番地

(72) 発明者

渡邊 大志

愛知県西春日井郡春日町大字落合字長畑 1  
番地 豊田合成株式会社内

(72) 発明者

浅井 誠

愛知県西春日井郡春日町大字落合字長畑 1  
番地 豊田合成株式会社内

(72) 発明者

柴田 直樹

愛知県西春日井郡春日町大字落合字長畑 1  
番地 豊田合成株式会社内

(74) 代理人

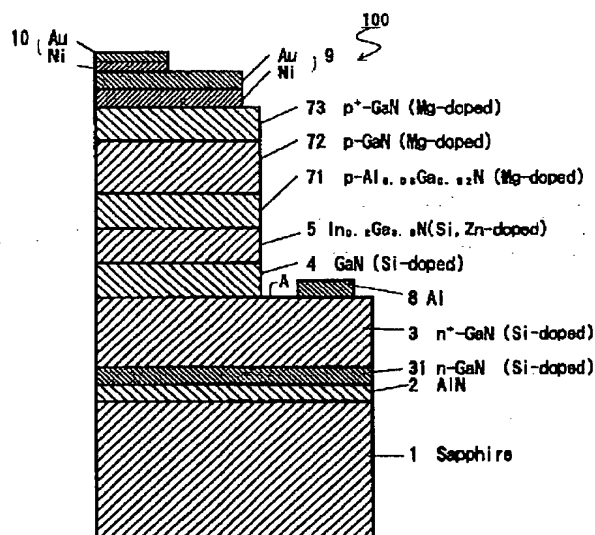
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(54) 【発明の名称】 3 族窒化物化合物半導体発光素子

(57) 【要約】

【課題】 青色発光素子の発光強度の増加及び発光効率の向上

【解決手段】 バッファ層 2 の上に、膜厚約  $0.6 \mu\text{m}$  の Si 濃度  $2 \times 10^{18}/\text{cm}^3$ 、電子濃度  $2 \times 10^{18}/\text{cm}^3$  の GaN の n 層 (第 1 低不純物濃度層) 3 1 を形成した後、その上に、順次、膜厚約  $4.0 \mu\text{m}$ 、Si 濃度  $4 \times 10^{18}/\text{cm}^3$ 、電子濃度  $2 \times 10^{18}/\text{cm}^3$  の GaN の高キャリア濃度 n<sup>+</sup> 層 (高不純物濃度層) 3、膜厚約  $0.5 \mu\text{m}$  の Si 濃度  $1 \times 10^{18}/\text{cm}^3$ 、電子濃度  $5 \times 10^{17}/\text{cm}^3$  の GaN の n 層 (第 2 低不純物濃度層) 4、膜厚約  $100 \text{ nm}$  の  $\text{In}_{0.20}\text{Ga}_{0.80}\text{N}$  の発光層 5、 $\text{Al}_{0.08}\text{Ga}_{0.92}\text{N}$  の p 伝導型のクラッド層 7 1、GaN の第 1 コンタクト層 7 2、GaN の p<sup>+</sup> 伝導形の第 2 コンタクト層 7 3 を形成した。n 層 (第 1 低不純物濃度層) 3 1 により発光層 5 の結晶性を向上でき、且つ、n<sup>+</sup> 層 3 にコンタクト電極を形成したので抵抗が小さく、駆動電圧の低下、発光効率の向上が達成できた。



## 【特許請求の範囲】

【請求項1】基板上に形成された3族窒化物半導体から成るn層、発光層、p層とを有する発光素子において、前記n層、前記p層のうち前記基板に近い方に形成される層を、前記基板に近い方から、不純物無添加を含む低濃度に不純物を添加した第1低不純物濃度層と、その第1低不純物濃度層の上に形成され、高濃度に不純物を添加した高不純物濃度層とを有する構成とし、前記高不純物濃度層に対してコンタクト電極を形成したことを特徴とする発光素子。

【請求項2】前記高不純物濃度層と前記発光層との間には、低濃度に不純物を添加した第2低不純物濃度層が形成されていることを特徴とする請求項1に記載の発光素子。

【請求項3】前記第1低不純物濃度層のキャリア濃度は $2 \times 10^{18}/\text{cm}^3$ 以下であることを特徴とする請求項1又は請求項2に記載の発光素子。

【請求項4】前記第1低不純物濃度層の厚さは、 $100 \text{ \AA}$ ～ $2 \mu\text{m}$ であることを特徴とする請求項1又は請求項2に記載の発光素子。

【請求項5】前記高不純物濃度層のキャリア濃度は $1 \times 10^{16}$ ～ $1 \times 10^{19}/\text{cm}^3$ であることを特徴とする請求項1又は請求項2に記載の発光素子。

【請求項6】前記高不純物濃度層の厚さは $0.5 \sim 10 \mu\text{m}$ であることを特徴とする請求項1又は請求項2に記載の発光素子。

【請求項7】前記第1低不純物濃度層の不純物濃度は $4 \times 10^{18}/\text{cm}^3$ 以下であることを特徴とする請求項1又は請求項2に記載の発光素子。

【請求項8】前記基板に近い方に形成される層はn伝導形を示すn層であることを特徴とする請求項1乃至請求項7のいずれかに記載の発光素子。

## 【発明の詳細な説明】

## 【0001】

【発明の属する技術分野】本発明は3族窒化物半導体を用いた半導体素子に関する。特に、発光輝度を向上させた発光素子に関する。

## 【0002】

【従来の技術】従来、青色や短波長領域の発光素子の材料としてAlGaInN系の化合物半導体を用いたものが知られている。その化合物半導体は直接遷移型であることから発光効率が高いこと、光の3原色の1つである青色及び緑色を発光色とすること等から注目されている。

【0003】AlGaInN系半導体においても、Mgをドーピングして電子線を照射したり、熱処理によりp型化できる。この結果、AlGaInNのp伝導型のクラッド層と、ZnとSiドーピングのInGaInNの発光層と、GaInNのn層とを用いたダブルヘテロ構造を有する発光ダイオード(LED)が知られている。この発光ダイオードはサファイア基板の上にバッファ層、シリコンを高濃度に添加したn<sup>+</sup>形GaInN層、

シリコンを添加したn形GaInN層からなるクラッド層、InGaInNから成る発光層、p形AlGaInNのクラッド層、p形GaInNの第1コンタクト層、p<sup>+</sup>形GaInNの第2コンタクト層を形成したものである。

## 【0004】

【発明が解決しようとする課題】しかし、このような構造の発光ダイオードは、発光強度が未だ小さいという問題があった。そこで、本発明者らはこの発光素子の結晶性について研究を重ねた結果、次のことが新しく分かった。バッファ層の上にシリコンを高濃度に添加したn<sup>+</sup>形GaInN層を形成して、その上に順次、上の層を形成している。この結果、n<sup>+</sup>形GaInN層が不純物を多量に含んでいる結果、結晶性が良くなく、従って、その上に形成される各層の結晶性も良くないということが判明した。そこで、バッファ層を除いて、基板上に最初に形成される層となるべし不純物濃度の低い層とすれば、以後、その上に形成される各層の結晶性が良くなり、発光輝度、発光効率が向上することが判明した。

【0005】従って、本発明は、上記の知見に基づいて成されたものであり、本発明の目的は、発光素子の各層の結晶性を向上することで、発光輝度及び発光効率を向上させることである。

## 【0006】

【課題を解決するための手段】本発明は、基板上に形成された3族窒化物半導体から成るn層、発光層、p層とを有する発光素子において、n層、p層のうち基板に近い方に形成される層を、基板に近い方から、不純物無添加を含む低濃度に不純物を添加した第1低不純物濃度層と、その第1低不純物濃度層の上に形成され、高濃度に不純物を添加した高不純物濃度層とを有する構成とし、高不純物濃度層に対してコンタクト電極を形成したことを特徴とする。

【0007】上記の構成において、高不純物濃度層と発光層との間には、低濃度に不純物を添加した第2低不純物濃度層が形成されていても良い。発光層を成長させる基礎となる層の不純物濃度を低くしたのでその層の結晶性が良く、従って、その上に成長される発光層の結晶性も良くなる。

【0008】上記の構成において、第1低不純物濃度層のキャリア濃度は $2 \times 10^{18}/\text{cm}^3$ 以下が望ましい。この時、その上に形成される各層の結晶性が改善される。又、低不純物濃度層の厚さは、 $100 \text{ \AA}$ ～ $2 \mu\text{m}$ が望ましい。 $100 \text{ \AA}$ より薄いとその上に形成される各層の結晶性の改善の効果が低く、 $2 \mu\text{m}$ 以上となると、クラックを発生させずにその上に成長できる各層の厚さが制限されるために望ましくない。

【0009】上記の構成において、高不純物濃度層のキャリア濃度は $1 \times 10^{16}$ ～ $1 \times 10^{19}/\text{cm}^3$ であることが望ましい。この層にコンタクト電極が形成される。よって、この層は抵抗率が小さい程望ましいが、キャリア濃度を

$1 \times 10^{16}/\text{cm}^3$ 以上とすると、結晶性が悪くなり、その上に形成される層の結晶性が低下するので望ましくない。キャリア濃度が $1 \times 10^{16}/\text{cm}^3$ 以下となると、適正な層の厚さで抵抗を低下させることができないので望ましくない。又、その高不純物濃度層の厚さは $0.5 \sim 10 \mu\text{m}$ であることが望ましい。 $0.5 \mu\text{m}$ より薄いとエッチングによりその層を露出して、その層にコンタクト電極を形成するのが困難となり望ましくない。又、 $10 \mu\text{m}$ より厚いとその上に形成される各層をクラックを発生させずに成長させることが困難となるので望ましくない。

【0010】さらに、上記構成において、第1低不純物濃度層の不純物濃度は $4 \times 10^{18}/\text{cm}^3$ 以下であることが望ましい。不純物濃度は $4 \times 10^{18}/\text{cm}^3$ を越えると、その上に形成される各層の結晶性が低下するので望ましくない。又、基板に近い方に形成される層はn伝導形のn層でもp伝導形のp層でも良いが、p形活性化の点から言えば、基板に近い方をn層とする方が製造が容易である。基板に近い方の層をn層とした場合には、上記のキャリア濃度は電子濃度を意味し、上記の不純物はドナー不純物を意味する。又、基板に近い方の層をp層とした場合には、上記のキャリア濃度はホール濃度を意味し、上記の不純物はアクセプタ不純物を意味する。上記のキャリア濃度、不純物濃度、層の厚さの数値範囲は、n層でもp層でも共に、それぞれ、望ましい範囲である。

#### 【0011】

【発明の作用及び効果】上述したように、発光層の成長の基礎となる層を不純物無添加を含む不純物濃度が低い層としたので、その層の結晶性が向上する。従って、その第1低不純物濃度層の上に形成される各層の結晶性が向上し、特に、発光層の結晶性が良くなる結果、発光輝度、発光効率が向上した。又、その第1低不純物濃度層の上に不純物濃度が高い層を形成し、その層にコンタクト電極を設けたために、キャリアはその第1不純物濃度層を通過することがないために、抵抗による電圧低下、抵抗損が抑制され、発光効率が向上した。

#### 【0012】

【発明の実施の形態】以下、本発明を具体的な実施例に基づいて説明する。なお本発明は下記実施例に限定されるものではない。図1は本願実施例の発光素子100全体図を示す。発光素子100は、サファイア基板1を有しており、そのサファイア基板1上に $0.05 \mu\text{m}$ のAlNバッファ層2が形成されている。

【0013】そのバッファ層2の上には、順に、膜厚約 $0.6 \mu\text{m}$ のシリコン濃度 $2 \times 10^{18}/\text{cm}^3$ 、電子濃度 $1 \times 10^{18}/\text{cm}^3$ のシリコン(Si)ドーパGaNから成るn層(第1低不純物濃度層)31、膜厚約 $4.0 \mu\text{m}$ 、シリコン濃度 $4 \times 10^{18}/\text{cm}^3$ 、電子濃度 $2 \times 10^{18}/\text{cm}^3$ のシリコン(Si)ドーパGaNから成る高キャリア濃度 $n^+$ 層(高不純物濃度層)3、膜厚約 $0.5 \mu\text{m}$ のシリコン濃度 $1 \times 10^{18}/\text{cm}^3$ 、電子濃度 $5 \times 10^{17}/\text{cm}^3$ のシリコン(Si)ドーパのGaNから

成るn層(第2低不純物濃度層)4、膜厚約 $100 \text{nm}$ 、亜鉛(Zn)とシリコン(Si)ドーパがそれぞれ、 $5 \times 10^{18}/\text{cm}^3$ にドーパされた $\text{In}_{0.20}\text{Ga}_{0.80}\text{N}$ から成る発光層5、膜厚約 $10 \text{nm}$ 、ホール濃度 $2 \times 10^{17}/\text{cm}^3$ 、マグネシウム(Mg)濃度 $5 \times 10^{19}/\text{cm}^3$ ドーパの $\text{Al}_{0.08}\text{Ga}_{0.92}\text{N}$ から成るp伝導形のクラッド層71、膜厚約 $35 \text{nm}$ 、ホール濃度 $3 \times 10^{17}/\text{cm}^3$ のマグネシウム(Mg)濃度 $5 \times 10^{19}/\text{cm}^3$ ドーパのGaNから成る第1コンタクト層72、膜厚約 $5 \text{nm}$ 、ホール濃度 $6 \times 10^{17}/\text{cm}^3$ のマグネシウム(Mg)濃度 $1 \times 10^{20}/\text{cm}^3$ ドーパのGaNから成る $p^+$ 伝導形の第2コンタクト層73が形成されている。そして、第2コンタクト層73の上面全体にNi/Auの2重層からなる透明電極9が形成されその透明電極9の隅の部分にNi/Auの2重層からなるボンディングのためのパッド10が形成されている。又、 $n^+$ 層3上にはAlから成る電極8が形成されている。

【0014】次に、この構造の半導体素子の製造方法について説明する。上記発光素子100は、有機金属気相成長法(以下MOVPE)による気相成長により製造された。用いられたガスは、アンモニア( $\text{NH}_3$ )、キャリアガス( $\text{H}_2$ )、トリメチルガリウム( $\text{Ga}(\text{CH}_3)_3$ ) (以下「TMG」と記す)、トリメチルアルミニウム( $\text{Al}(\text{CH}_3)_3$ ) (以下「TMA」と記す)、トリメチルインジウム( $\text{In}(\text{CH}_3)_3$ ) (以下「TMI」と記す)、シラン( $\text{SiH}_4$ )とジエチル亜鉛( $\text{Zn}(\text{C}_2\text{H}_5)_2$ ) (以下「DEZ」と記す)とシクロペンタジエニルマグネシウム( $\text{Mg}(\text{C}_5\text{H}_5)_2$ ) (以下「 $\text{CP}_2\text{Mg}$ 」と記す)である。

【0015】まず、有機洗浄及び熱処理により洗浄したa面を主面とし、単結晶のサファイア基板1をMOVPE装置の反応室に載置されたサセクタに装着する。次に、常圧で $\text{H}_2$ を流速2 liter/分で約30分間反応室に流しながら温度 $1100^\circ\text{C}$ でサファイア基板1をベーキングした。

【0016】次に、温度を $400^\circ\text{C}$ まで低下させて、 $\text{H}_2$ を20 liter/分、 $\text{NH}_3$ を10 liter/分、TMAを $1.8 \times 10^{-5}$ モル/分で約90秒間供給してAlNのバッファ層2を約 $0.05 \mu\text{m}$ の厚さに形成した。次に、サファイア基板1の温度を $1100^\circ\text{C}$ に保持し、 $\text{H}_2$ を20 liter/分、 $\text{NH}_3$ を10 liter/分、TMGを $1.12 \times 10^{-4}$ モル/分、 $\text{H}_2$ ガスにより $0.86 \text{ppm}$ に希釈されたシランを $20 \times 10^{-9}$ モル/分で36分導入し、膜厚約 $0.6 \mu\text{m}$ 、電子濃度 $1 \times 10^{18}/\text{cm}^3$ 、シリコン濃度 $2 \times 10^{18}/\text{cm}^3$ のシリコン(Si)ドーパGaNから成るn層31を形成した。

【0017】次に、サファイア基板1の温度を $1150^\circ\text{C}$ に保持し、 $\text{H}_2$ を20 liter/分、 $\text{NH}_3$ を10 liter/分、TMGを $1.7 \times 10^{-4}$ モル/分、 $\text{H}_2$ ガスにより $0.86 \text{ppm}$ に希釈されたシランを $20 \times 10^{-8}$ モル/分で40分導入し、膜厚約 $4.0 \mu\text{m}$ 、電子濃度 $1 \times 10^{18}/\text{cm}^3$ 、シリコン濃度 $4 \times 10^{18}/\text{cm}^3$ のシリコン(Si)ドーパGaNから成る高キャリア濃度 $n^+$ 層3を形成した。

【0018】上記の高キャリア濃度 $n^+$ 層3を形成した

後、続いて温度を1100°Cに保持し、 $H_2$ を20 liter/分、 $NH_3$ を10 liter/分、TMGを $1.12 \times 10^{-4}$ モル/分、 $H_2$ ガスにより0.86ppmに希釈されたシランを $10 \times 10^{-9}$ モル/分で30分導入し、膜厚約0.5  $\mu m$ 、電子濃度 $5 \times 10^{17}/cm^3$ 、シリコン濃度 $1 \times 10^{18}/cm^3$ のシリコン(Si)ドーパGaNから成るn層4を形成した。

【0019】続いて、温度を800°Cに保持し、 $N_2$ 又は $H_2$ を20 liter/分、 $NH_3$ を10 liter/分、TMGを $0.2 \times 10^{-4}$ モル/分、TMIを $1.6 \times 10^{-4}$ モル/分、 $H_2$ ガスにより0.86ppmに希釈されたシランを $10 \times 10^{-8}$ mol/分で、DEZを $2 \times 10^{-4}$ モル/分で、30分間供給して厚さ100nmのシリコンと亜鉛が、それぞれ、 $5 \times 10^{18}/cm^3$ にドーパした $In_{0.20}Ga_{0.80}N$ から成る発光層5を形成した。

【0020】続いて、温度を1100°Cに保持し、 $N_2$ 又は $H_2$ を20 liter/分、 $NH_3$ を10 liter/分、TMGを $1.12 \times 10^{-4}$ モル/分、TMAを $0.47 \times 10^{-4}$ モル/分、及び、 $CP_2Mg$ を $2 \times 10^{-5}$ モル/分で0.6分間導入し、膜厚約10nmのマグネシウム(Mg)ドーパの $Al_{0.08}Ga_{0.92}N$ から成るクラッド層71を形成した。クラッド層71のマグネシウム濃度は $5 \times 10^{19}/cm^3$ である。この状態では、クラッド層71は、まだ、抵抗率 $10^8 \Omega cm$ 以上の絶縁体である。

【0021】次に、温度を1100°Cに保持し、 $N_2$ 又は $H_2$ を20 liter/分、 $NH_3$ を10 liter/分、TMGを $1.12 \times 10^{-4}$ モル/分、及び、 $CP_2Mg$ を $2 \times 10^{-5}$ モル/分で40秒間導入し、膜厚約35nmのマグネシウム(Mg)ドーパのGaNから成る第1コンタクト層72を形成した。第1コンタクト層72のマグネシウム濃度は $5 \times 10^{19}/cm^3$ である。この状態では、第1コンタクト層72は、まだ、抵抗率 $10^8 \Omega cm$ 以上の絶縁体である。

【0022】次に、温度を1100°Cに保持し、 $N_2$ 又は $H_2$ を20 liter/分、 $NH_3$ を10 liter/分、TMGを $1.12 \times 10^{-4}$ モル/分、及び、 $CP_2Mg$ を $4 \times 10^{-5}$ モル/分で18秒間導入し、膜厚約5nmのマグネシウム(Mg)ドーパのGaNから成る $p^+$ の第2コンタクト層73を形成した。第2コンタクト層73のマグネシウム濃度は $1 \times 10^{20}/cm^3$ である。この状態では、第2コンタクト層73は、まだ、抵抗率 $10^8 \Omega cm$ 以上の絶縁体である。

【0023】次に、電子線照射装置を用いて、第2コンタクト層73、第1コンタクト層72及びクラッド層71に様に電子線を照射した。電子線の照射条件は、加速電圧約10KV、資料電流1  $\mu A$ 、ビームの移動速度0.2m/sec、ビーム径60  $\mu m \phi$ 、真空度 $5.0 \times 10^{-5}$ Torrである。この電子線の照射により、第2コンタクト層73、第1コンタクト層72及びクラッド層71は、それぞれ、ホール濃度 $6 \times 10^{17}/cm^3$ 、 $3 \times 10^{17}/cm^3$ 、 $2 \times 10^{17}/cm^3$ 、抵抗率 $2 \Omega cm$ 、 $1 \Omega cm$ 、 $0.7 \Omega cm$ のp伝導型半導体となった。このようにして多層構造のウエハが得られた。

【0024】次に、図2に示すように、第2コンタクト層73の上に、真空蒸着によりTi(チタン)層111を厚さ1000Åに形成し、その上にNi(ニッケル)層112

を厚さ1  $\mu m$ に形成する。そして、Ni層112の上にフォトレジスト12を塗布し、フォトリソグラフにより、図2に示すように、第2コンタクト層73上において、高キャリア濃度 $n^+$ 層3に対する電極形成部位A'のフォトレジスト12を除去した。次に、図3に示すように、フォトレジスト12によって覆われていないTi層111とNi層112とを酸でウェットエッチングして除去した。

【0025】次に、Ti層111とNi層112によって覆われていない部位の第2コンタクト層73、第1コンタクト層72、クラッド層71、発光層5、n層4を、 $BCl_3$ ガスでドライエッチングした後、続いて、Arでドライエッチングした。この工程で、図4に示すように、高キャリア濃度 $n^+$ 層3に対する電極取出しのための孔Aが形成された。その後、マスクとしてのフォトレジスト12、Ti層111及びNi層112を除去した。

【0026】次に、様にフォトレジストを塗布した後、フォトリソグラフィ工程により、透明電極9を形成する部分に窓を開けた。この後、様にNi/Auの2層を蒸着し、フォトレジストを除去して、即ち、リフトオフ法により、第2コンタクト層73の上に透明電極9を形成した。そして、その透明電極9の一部にNi/Auの2層を蒸着してパッド10を形成した。一方、 $n^+$ 層3に対しては、同様な工程により、アルミニウムを蒸着して電極8を形成した。その後、上記のごとく処理されたウエハは、各素子毎に切断され、図1に示す構造の発光ダイオードを得た。この発光素子は駆動電流20mAで発光ピーク波長430nm、発光強度1500mCdであった。従来構造のLEDに比べて発光強度は3倍になった。

【0027】尚、GaNのn層31を設けて上記構成の発光素子を形成した場合の最上層の第2コンタクト層73の表面モロロジを顕微鏡で観察した。その表面顕微鏡写真を図5に示す。又、従来の発光素子のように、n層31を設けずに、バッファ層2の上に直接、 $n^+$ 層3を形成して、発光素子を形成した場合の最上層の第2コンタクト層73の表面モロロジを顕微鏡で観察した。その表面顕微鏡写真を図6に示す。いずれも200倍の顕微鏡写真である。

【0028】この写真から分かるように、n層31を設けてその上に各層を積層させた方が結晶性が良くなっていることが理解される。

【0029】上記実施例において、n層4を高キャリア濃度 $n^+$ 層3と発光層5との間に形成しているが、高キャリア濃度 $n^+$ 層3の不純物キャリア濃度が比較的低い場合には、高キャリア濃度 $n^+$ 層3の上に直接、発光層5を成長させても良い。上記実施例において、n層31には、シリコンを $2 \times 10^{18}/cm^3$ に添加して電子濃度を $1 \times 10^{18}/cm^3$ としているが、無添加であっても良い。シリコン濃度が $2 \times 10^{18}/cm^3$ 、電子濃度が $1 \times 10^{18}/cm^3$ よりも小さい時には、その上に成長する各層の結晶性が良好



となることが確認されている。

【0030】さらに、n層31の厚さは0.6  $\mu\text{m}$  としているが、n層31はその上に順次成長する各層の結晶性を改善するために存在するために、100  $\text{\AA}$ ~2  $\mu\text{m}$  範囲で結晶性の改善の効果があることが確認されている。上記実施例において、高キャリア濃度 $n^+$ 層3のキャリア濃度は $2 \times 10^{18}/\text{cm}^3$ 、シリコン濃度を $4 \times 10^{18}/\text{cm}^3$ としたが、キャリア濃度は $1 \times 10^{16}$ ~ $1 \times 10^{19}/\text{cm}^3$ 、シリコン濃度は $1 \times 10^{17}$ ~ $1 \times 10^{20}/\text{cm}^3$ の範囲で、その上に成長する層の結晶性を改善でき、且つ、抵抗を小さくすることができる。又、高キャリア濃度 $n^+$ 層3の厚さを4.0  $\mu\text{m}$ としたが、キャリア濃度と同一の観点からその高キャリア濃度 $n^+$ 層3の厚さは0.5~10  $\mu\text{m}$ の範囲が最適である。

【0031】n層4は、シリコン濃度 $1 \times 10^{18}/\text{cm}^3$ 、電子濃度 $5 \times 10^{17}/\text{cm}^3$ としたが、シリコン濃度 $2 \times 10^{16}$ ~ $2 \times 10^{19}/\text{cm}^3$ 、電子濃度 $1 \times 10^{16}$ ~ $1 \times 10^{19}/\text{cm}^3$ が適切な範囲である。又、厚さは、0.5  $\mu\text{m}$ としたが、0.5~2  $\mu\text{m}$ が望ましい。膜厚が0.5  $\mu\text{m}$ 以下となると発光強度が低下し、2  $\mu\text{m}$ 以上となると直列抵抗が高くなり過ぎ、電流を流すと発熱するので望ましくない。

【0032】上記実施例において、コンタクト層は2層構造としたが1層構造でも良い。発光層5には、 $\text{In}_{0.20}\text{Ga}_{0.80}\text{N}$ を用いたが2元、3元、4元のInGaAlNの3族窒化物半導体であれば構成元素の組成比は任意のものが使用できる。又、クラッド層71、第1コンタクト層72、第2コンタクト層73に関しては、発光層5よりもバンドギャップの広い半導体が要求される。これらの層も2元、3元、4元の3族窒化物半導体を用いることができる。又、n層31、 $n^+$ 層3、n層4も同様に、一般式 $\text{InGaAlN}$ で任意組成比の2元、3元、4元の3族窒化物半導体を用いることができる。

【0033】又、発光層5のシリコン濃度及び亜鉛濃度は、それぞれ、 $1 \times 10^{17}$ ~ $1 \times 10^{20}/\text{cm}^3$ が望ましい。 $1 \times 10^{17}/\text{cm}^3$ 以下であると、発光中心不足により発光効率が低下し、 $1 \times 10^{20}/\text{cm}^3$ 以上となると、結晶性が悪くなり、又、オージェ効果が発生するので望ましくない。さらに好ましくは $1 \times 10^{18}$ ~ $1 \times 10^{19}/\text{cm}^3$ の範囲が良い。又、シリコン(Si)の濃度は、亜鉛(Zn)に比べて、10倍~1/10が好ましく、さらに好ましくは1~1/10の間程度か、少ないほうがより望ましい。

【0034】上記の実施例では、発光層5は単層で構成したが、一般式 $\text{Al}_{x1}\text{Ga}_{y1}\text{In}_{1-x1-y1}\text{N}$  ( $0 \leq x1 \leq 1$ ,  $0 \leq y1 \leq 1$ ,  $0 \leq x1+y1 < 1$ )の井戸層と一般式 $\text{Al}_{x2}\text{Ga}_{y2}\text{In}_{1-x2-y2}\text{N}$  ( $0 \leq x2 \leq 1$ ,  $0 \leq y2 \leq 1$ ,  $0 \leq x2+y2 \leq 1$ )のバリア層とから成る単一又は多重量子井戸構造に構成しても良い。その場合に、井戸層又はバリア層にドナー不純物

とアクセプタ不純物を同時に添加しても良いし、井戸層にドナー不純物又はアクセプタ不純物を添加し、バリア層に、逆に、アクセプタ不純物又はドナー不純物を添加しても良い。又、本発明は発光ダイオードの他、レーザダイオードにも用いることができる。

【0035】アクセプタ不純物は、2族元素のベリリウム(Be)、マグネシウム(Mg)、亜鉛(Zn)、カドミウム(Cd)、水銀(Hg)を用いても良い。2族元素をアクセプタ不純物とした場合には、ドナー不純物として、4族元素である炭素(C)、シリコン(Si)、ゲルマニウム(Ge)、錫(Sn)、鉛(Pb)を用いることができる。又、4族元素をアクセプタ不純物とした場合には、ドナー不純物として、6族元素のイオウ(S)、セレン(Se)、テルル(Te)を用いることもできる。p型化は、電子線照射の他、熱アニーリング、 $\text{N}_2$ プラズマガス中での熱処理、レーザ照射により行うことができる。

【図面の簡単な説明】

【図1】本発明の具体的な第1実施例に係る発光ダイオードの構成を示した構成図。

【図2】同実施例の発光ダイオードの製造工程を示した断面図。

【図3】同実施例の発光ダイオードの製造工程を示した断面図。

【図4】同実施例の発光ダイオードの製造工程を示した断面図。

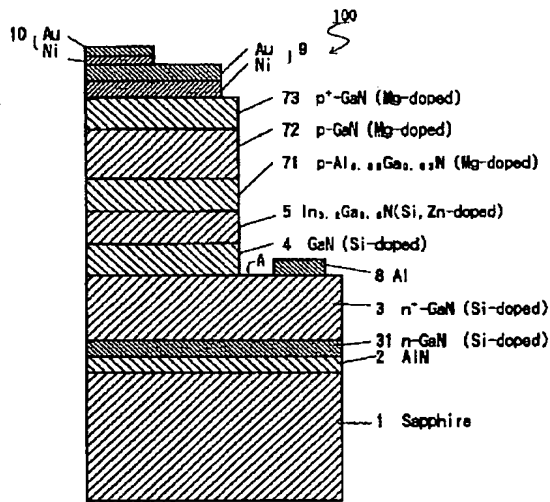
【図5】上記発光ダイオードにおいて第1低不純物濃度層(n層)を形成した場合の最上層の表面状態を観測した顕微鏡写真。

【図6】発光ダイオードにおいて第1低不純物濃度層(n層)を形成しない場合の最上層の表面状態を観測した顕微鏡写真。

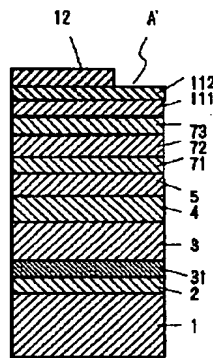
【符号の説明】

- 100 …半導体素子
- 1 …サファイア基板
- 2 …バッファ層
- 31 …n層(第1低不純物層)
- 3 …高キャリア濃度 $n^+$ 層(高不純物層)
- 4 …n層(第2低不純物層)
- 5 …発光層
- 6 …キャップ層
- 71 …クラッド層
- 72 …第1コンタクト層
- 73 …第2コンタクト層
- 8 …電極
- 9 …透明電極
- 10 …パッド

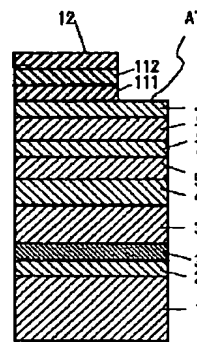
【図1】



【図2】



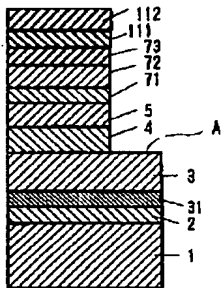
【図3】



【図6】

図面代用写真

【図4】



【図5】

図面代用写真

